Tuning of a DQW crab cavity

S. Verdu-Andres (BNL) for the Crab Cavity Work Package

Tuning of a DQW crab cavity for SPS beam tests - *goal*

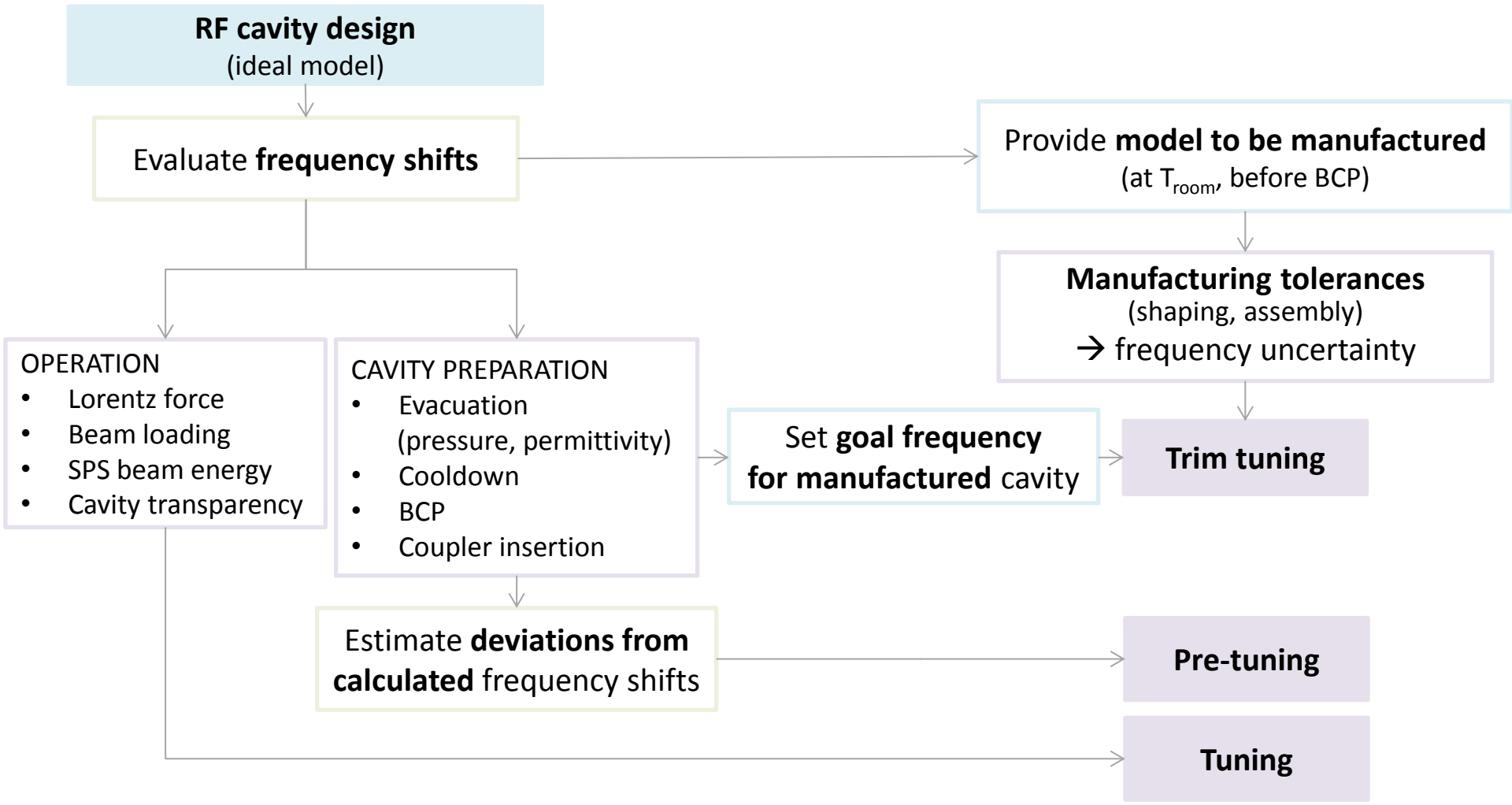
Resonant frequency of DQW crab cavity must be

400.79 MHz

for **cavity at 2K** and **under vacuum**
delivering nominal **deflecting voltage** of **3.34 MV**
with **450 GeV beam** of SPS

* for 270 GeV beam, the frequency must be 400.73 MHz → tuning mechanism

How to get cavity “in tune”?

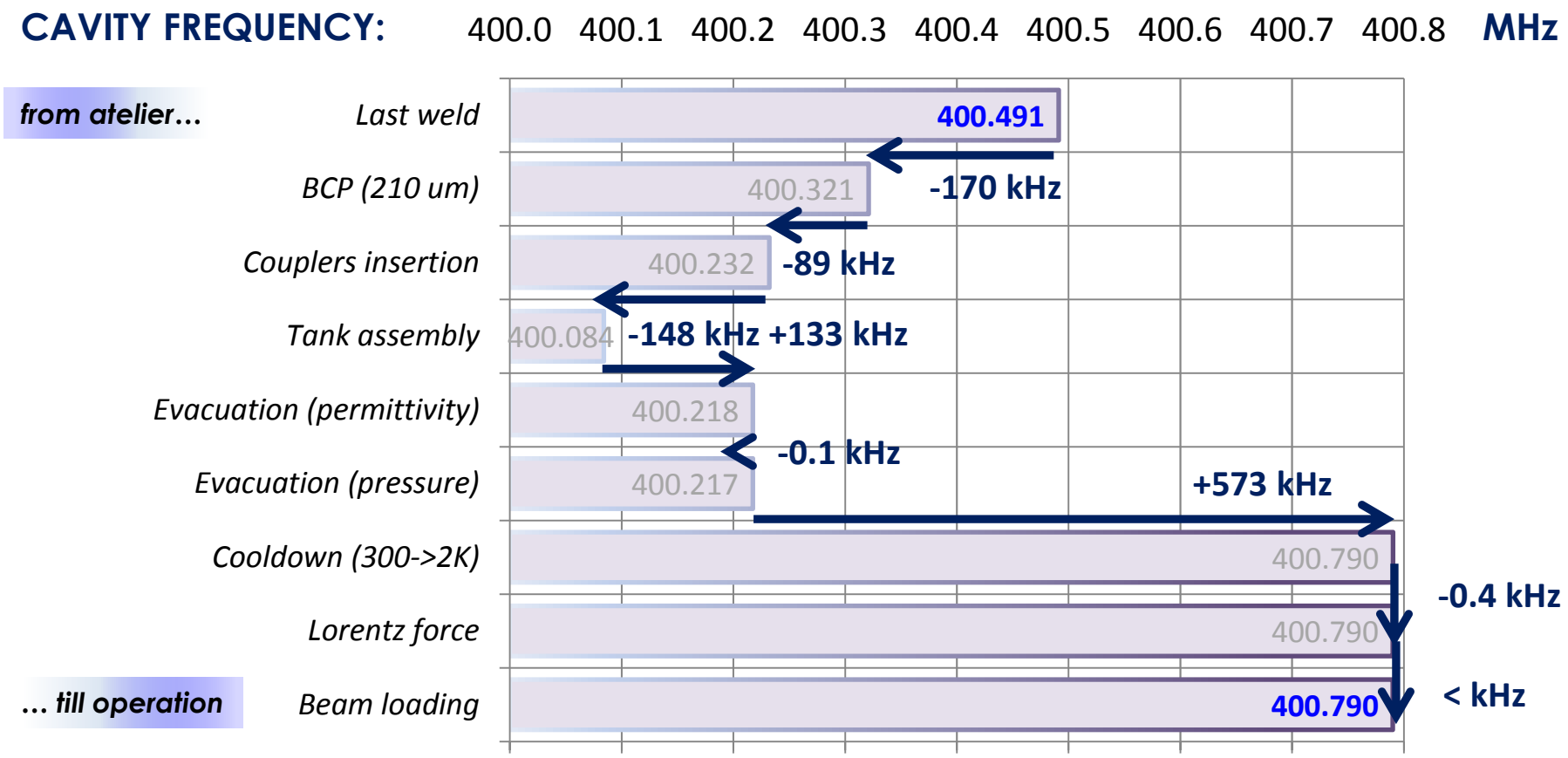


DOCUMENTATION

- Tuning procedure, Excel files: to **guide tuning** of cavity at different stages and assuming different scenarios
- Traveler: to **track cavity “frequency trip”** during manufacturing, preparation, tuning and operation

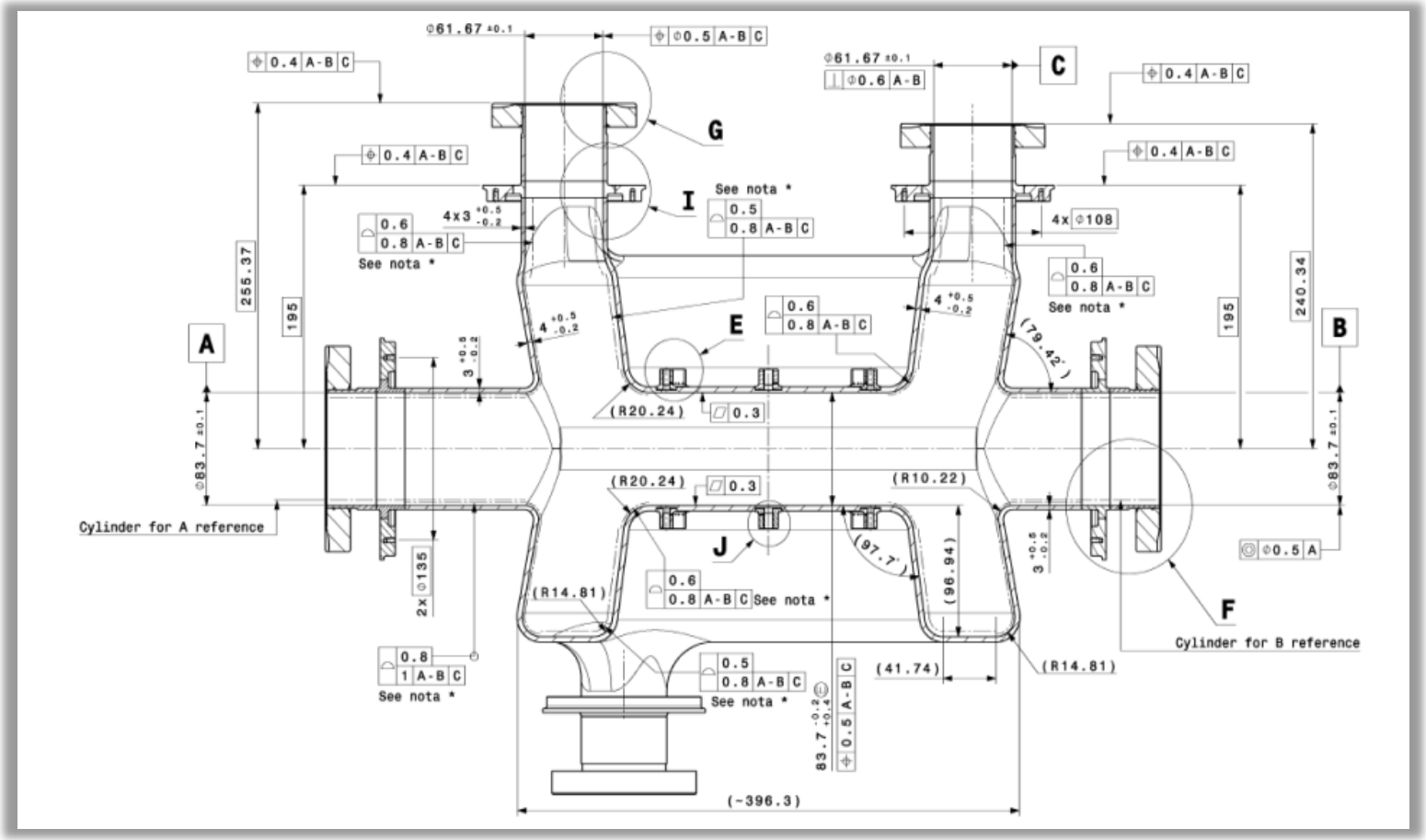
Frequency trip of a DQW – *from atelier till operation*

- Given the *goal frequency for* the cavity at *nominal operation*,
  the **frequency trip** provides: *goal frequency for the manufactured cavity.*



In addition to frequency shifts calculated and included in frequency trip table, other **processes** may also introduce ***frequency uncertainty/detuning***.

DETUNING	Freq shift range [kHz]
Subassemblies within tolerances (overall shape tol: ±0.4 mm)	[-340, +340]



DETUNING	***Freq shift range [kHz]***
Subassemblies within tolerances (overall shape tol: ±0.4 mm)	[-340, +340]
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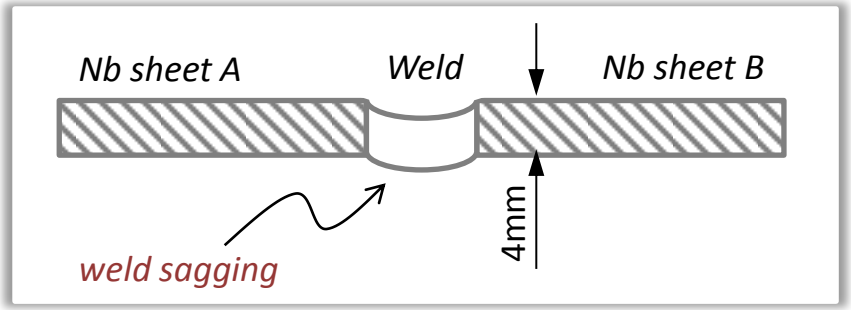

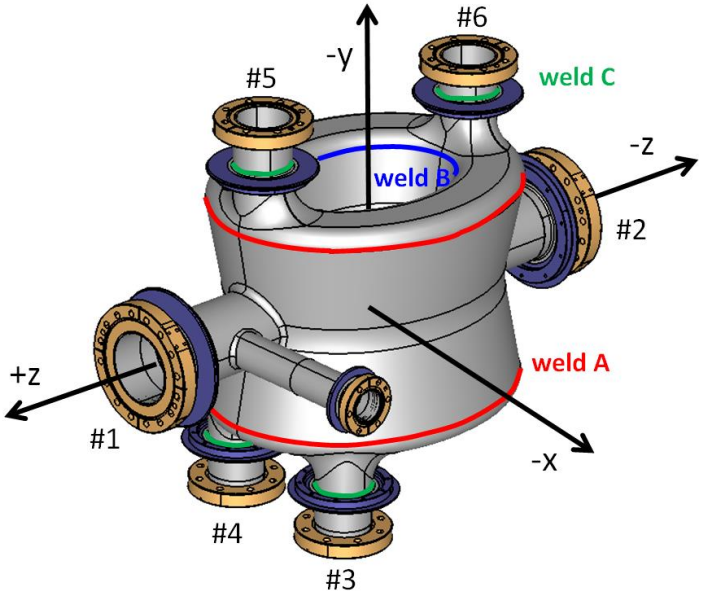

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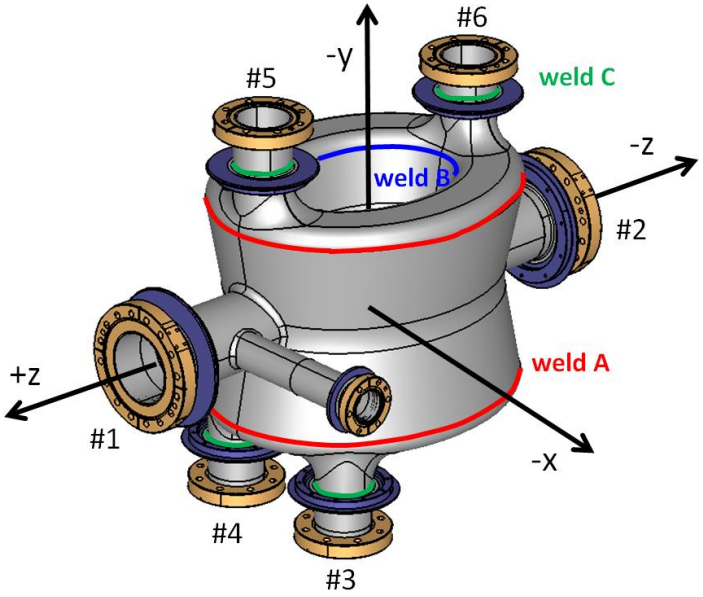
Bulk BCP 150 μm	[-40, +40]
Tank assembly and welding (±0.1 mm)	[-200, +200]

- *Dummy tank designed, fabricated and tested by CERN:*

- *Applied displacement* [mm] *to cavity ports and calculated new frequency* [kHz] (ACE3P):

$$\Delta f = 140(d_1 - d_2) + 580(d_3 + d_4) - 800d_5 - 380d_6$$



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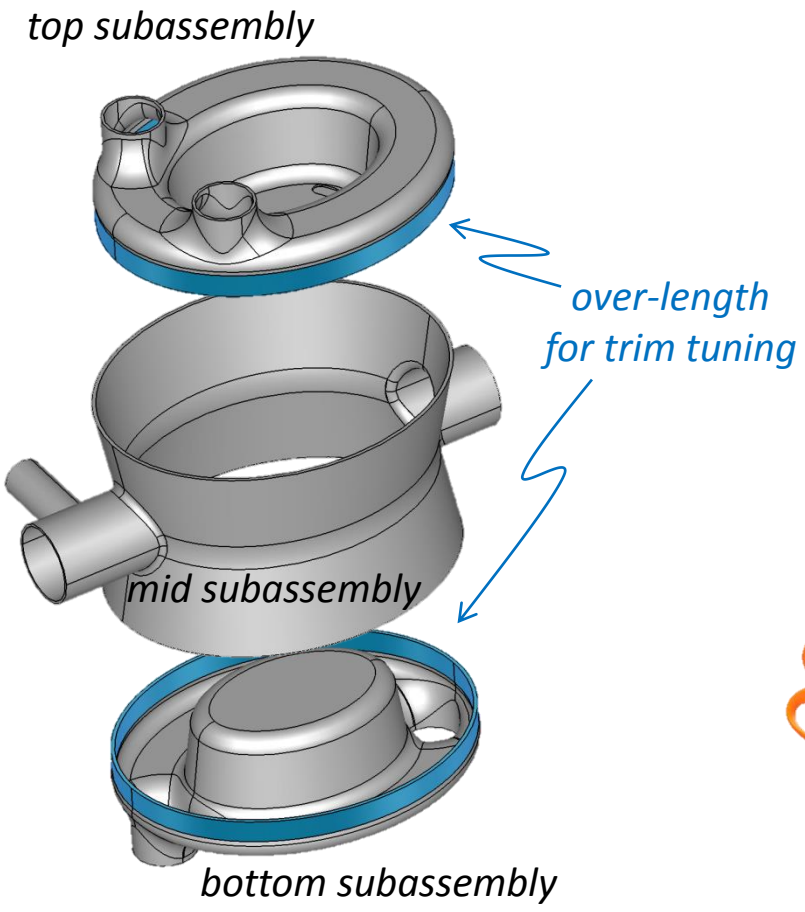
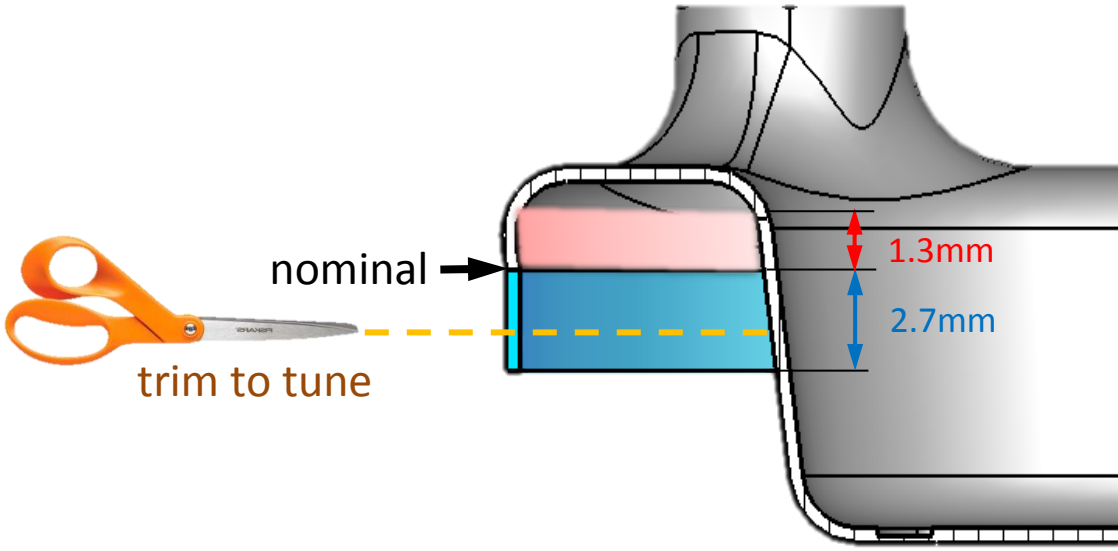
Operation in SPS (from 400.73-400.79 MHz for SPS beams of 120-450 GeV)	[-60, +0]

* Others that may bring a frequency shift:
baking, transportation, beam loading

- Deviations between calculated values and frequency shifts experienced by cavity.
  - **Tuning mechanisms** to *correct deviations* from expected frequency trip at different stages of cavity preparation.
- **Additional tuning** mechanism required for shifting cavity frequency during operation for: *SPS beams of different energy, cavity transparency*, etc.

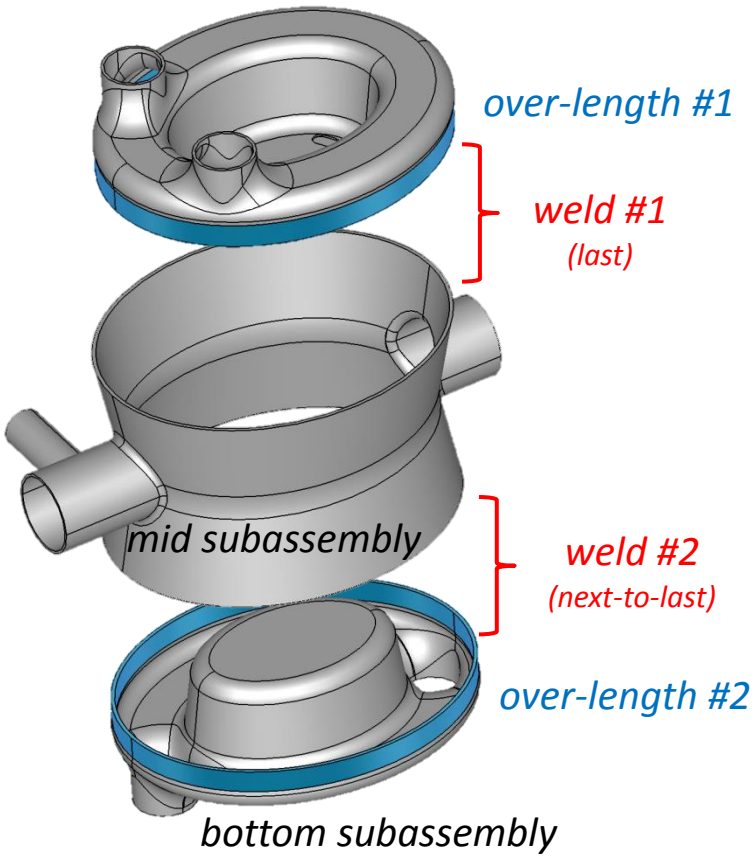
DETUNING	Freq shift range [kHz]	TUNING METHOD	Sensitivity [MHz/mm]	Max. displ [mm]	Tuning range [kHz]
Subassemblies within tolerances (overall shape tol: ±0.4 mm)	[-340, +340]				
		Trimming	**0.98**	[2.7, -1.3]	**[+2650, -1270]**

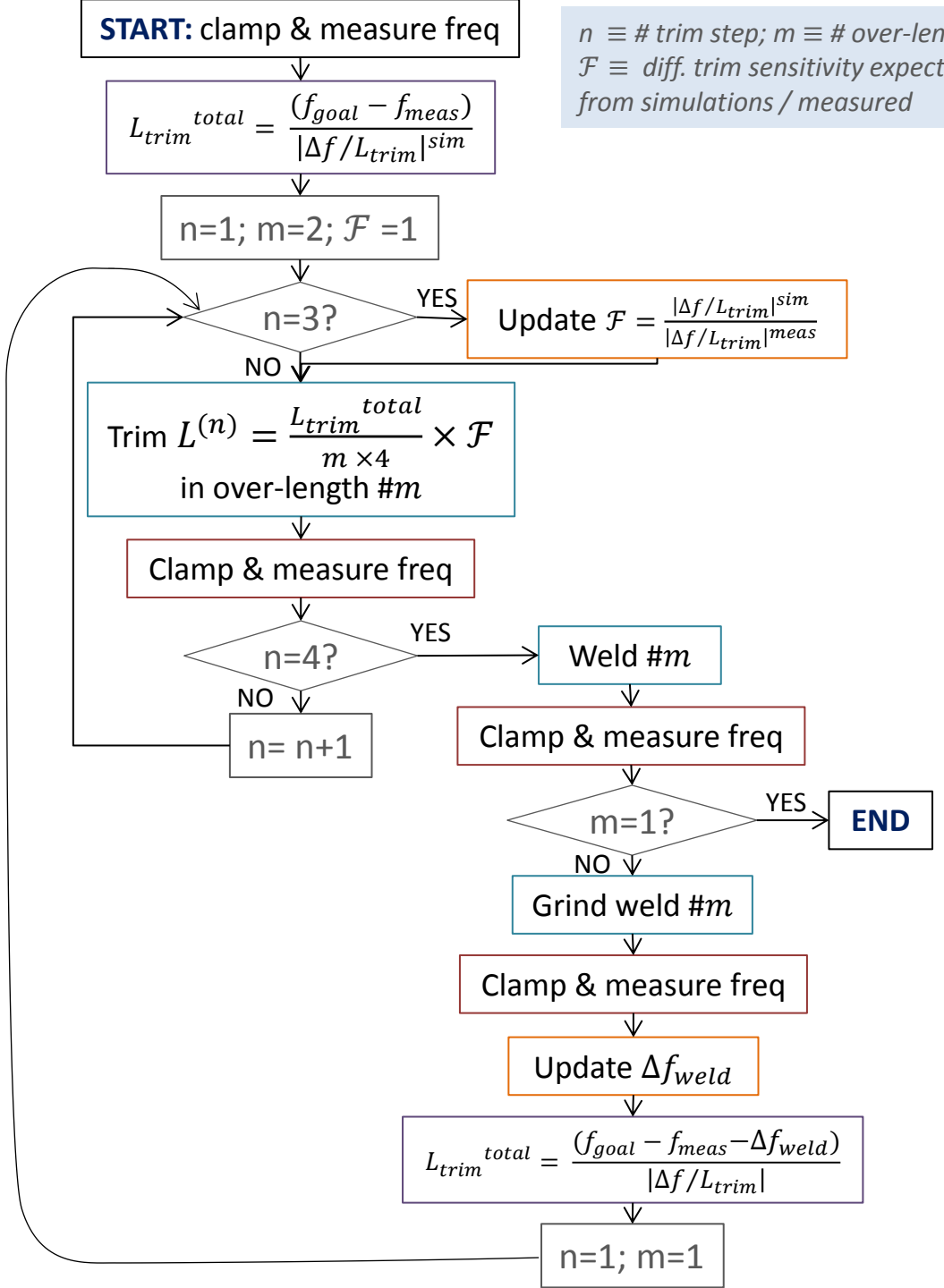




Trim tuning sequence

- Learn from next-to-last trim (Δf_{weld}, trim sensitivity)
- Check trim sensitivity in steps





n ≡ # trim step; m ≡ # over-length
$\mathcal{F}$ ≡ diff. trim sensitivity expected from simulations / measured

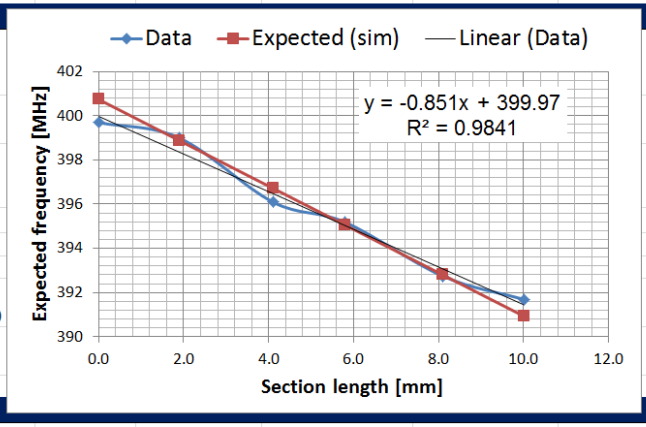
Guide for trimming – "last" weld trimming

- Corrects frequency according to $\varepsilon = f(H, p_{vapor}, T)$.
- Suggests length to be trimmed from calculated trim sensitivity and former data.
- Doing the same for trim sequence for "next-to-last" weld.
- Need to include expected displacement of electric field center due to asymmetric trim tuning.

TRIM TUNING - last weld

INPUT PARAMETERS

Frequency goal after weld for open ports and relative permittivity 1.00067	**fgoal_welded**	400.2366	**MHz**	(after final weld, open ports and relative permittivity of 1.00067) [1]
Expected freq shift due to final weld (bead + shrinkage)	**fweld**	0.5	**MHz**	(as learned in "next-to-last weld")
Freq goal before final weld for open ports and relative permittivity of 1.00067	**fgoal**	399.7366	**MHz**	(before final weld, open ports, and relative permittivity of 1.00067)
Initial length of "last" trim	**L**	10.00	**mm**	
Minimum trim length	**Lcutmin**	0.50	**mm**	
Error trim length	**eLcut**	0.25	**mm**	
Trim sensitivity (from simulations)	**$df_{sim}/dLcut$**	0.98	**MHz/mm**	(when reducing length of extra material in one side of a single weld line)
Trim sensitivity (from next-to-last weld)	**$df_{next2last}/dLcut$**	C1 from next2last weld	**MHz/mm**	(as learned in "next-to-last weld")



TRIM SEQUENCE for LAST TRIM SECTION

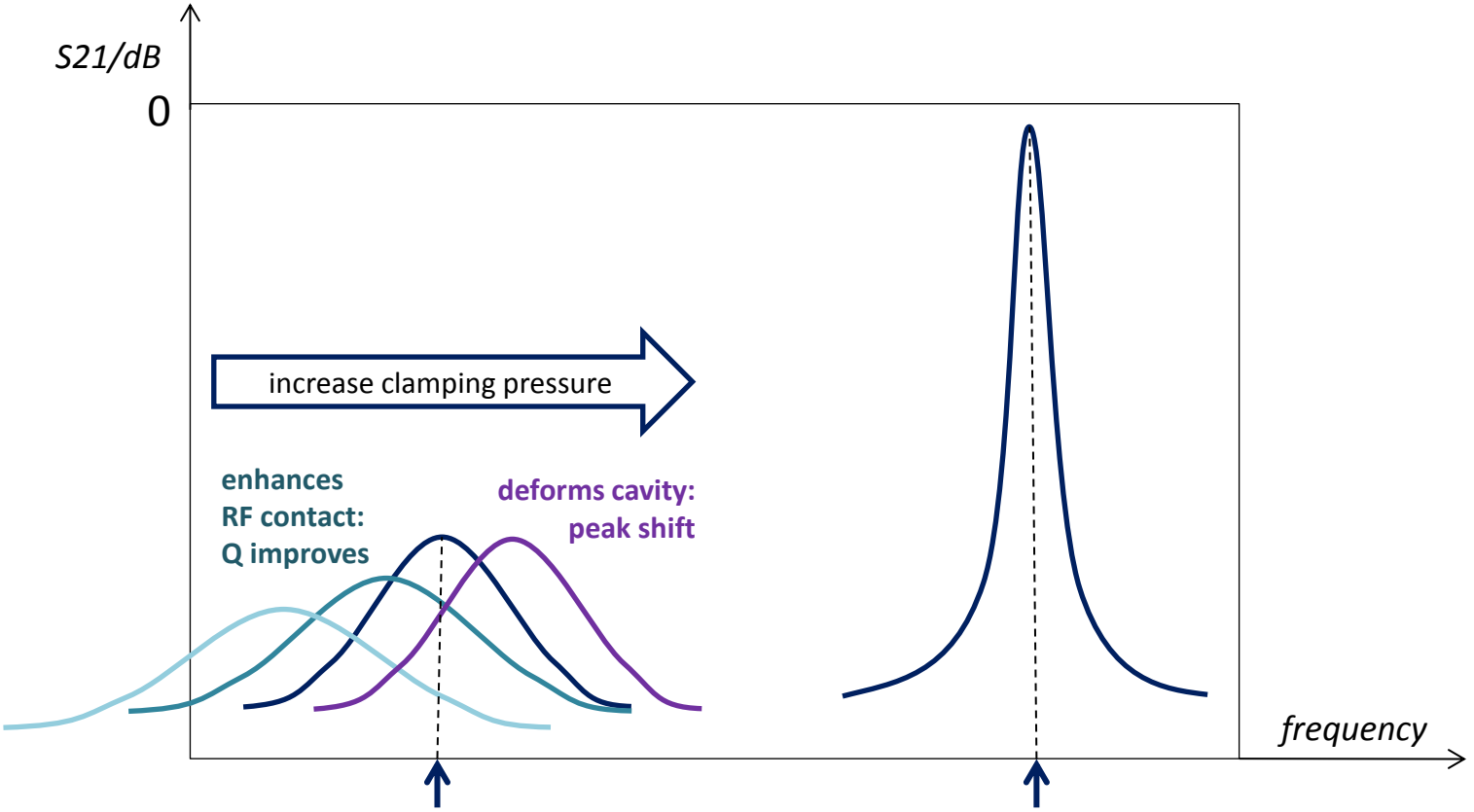
Trim step	Trim length (intended)	Trim length (measured)	Section length (measured)	Frequency expected from simulation	Frequency expected from data	Frequency measured	Temp	Vapor pressure [2]	Pressure	Humidity	Relative permittivity [3]	Frequency corrected with e_r	Suggested trim length	Feasible Lcutsug?
Nt	**Lcutint [mm]**	**Lcut [mm]**	**Lmeas [mm]**	**fexpsim [MHz]**	**fexpdata [MHz]**	**fmeas [MHz]**	**T [K]**	**pv [torr]**	**P [torr]**	**[%]**	**e_r [--]**	**fmeascorr [MHz]**	**Lcutsug [mm]**	**.cutsug > Lcutmin?)**
1	0.0	0.0	10.0	390.937	N/A	391.700	300	26.307	759	60	1.000708	391.693	8.21	YES
2	2.0	1.9	8.1	392.799	N/A	392.750	298	23.366	760	70	1.000721	392.740	7.14	YES
3	2.0	2.2	5.8	395.053	394.008	395.200	300	26.307	759	80	1.000767	395.181	4.65	YES
4	2.0	1.8	4.1	396.719	396.447	396.100	295	19.491	760	70	1.000699	396.094	3.72	YES
5	2.0	2.0	1.9	398.875	397.944	399.000	300	26.307	760	60	1.000709	398.992	0.76	YES
6	0.7	0.7	0.0	400.737	400.276	399.700	298	23.366	760	70	1.000721	399.690	0.05	NO
7														
etc														

REFERENCES

[1] S. Verdú-Andrés et al., "Specificities for Tuning a DQW Crab Cavity". EDMS No. 1569808 v.3 (2016).
[2] Formula provided by V. Shemelin, cross-checked with tables available on the web
[3] W. E. Phillips, "The Permittivity of Air at a Wavelength of 10 Centimeters," Proc. IRE (1950), 786 with corrections from the Discussion of this paper by C. M. Crain, Proc. IRE (1952) 164.

Trim tuning – *frequency measurement of clamped subassemblies*

- Ensure RF contact; avoid incorrect frequency read out due to deformation



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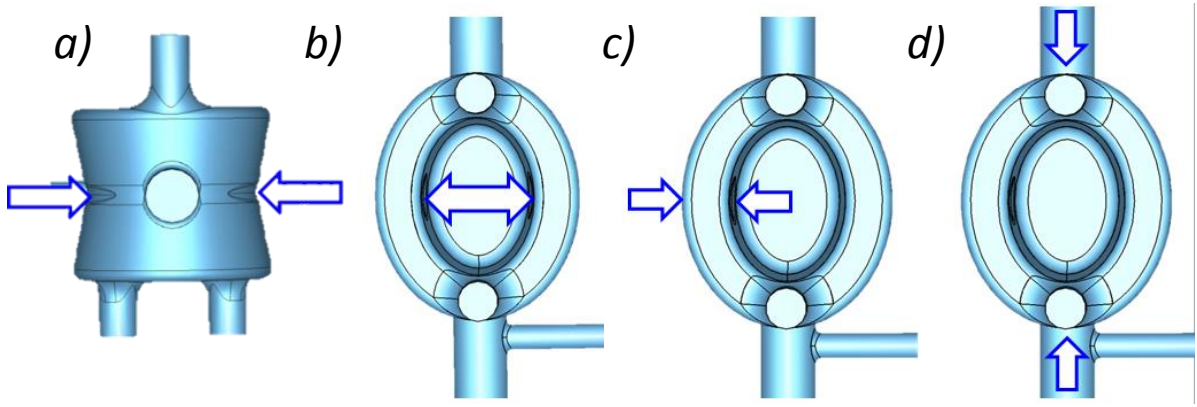
Final EB of cavity (weld sag ±0.2 mm & shrinkage ±0.1 mm)	[-40, +40] [-100, +100]				
Bulk BCP 150 μm	[-40, +40]				
		Pre-tuning outside of helium tank (on-going)			



0.11 MHz/mm **0.03 MHz/mm** **0.03 MHz/mm** **0.14 MHz/mm**

e) re-weld

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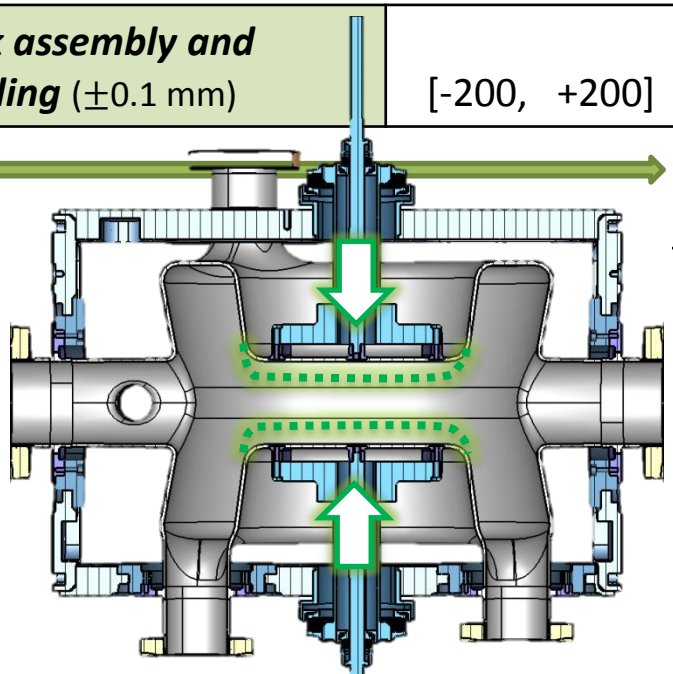
Bulk BCP 150 μm	[-40, +40]				
		Pre-tuning outside of helium tank			
Tank assembly and welding (±0.1 mm)	[-200, +200]				
		Pre-tuning in helium tank	**1.60**	±0.4 (under study)	**[+640,-640]**



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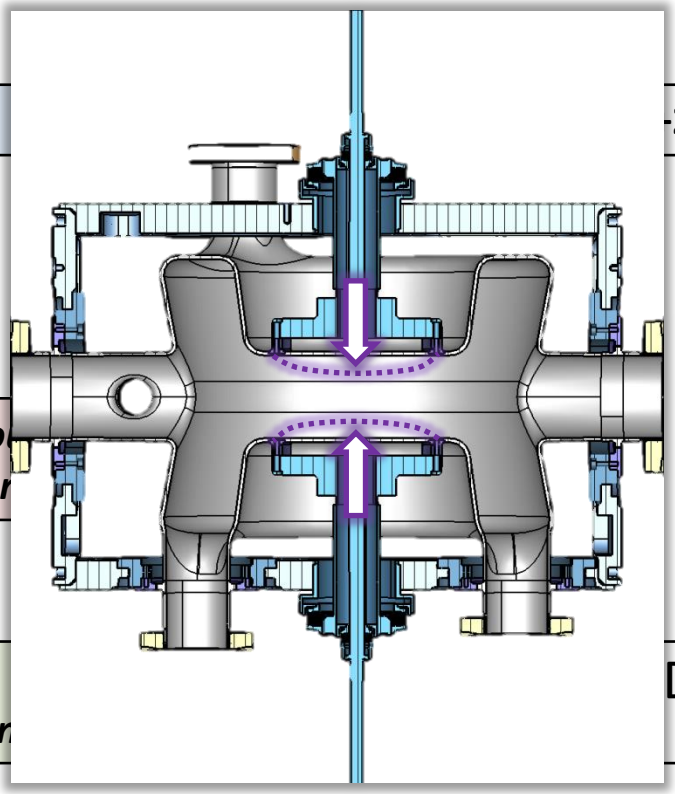
		Pre-tuning o… of helium tan…			
Tank assembly and welding (±0.1 mm)	[-200, +200]				
		Pre-tuning in helium tan…			**[+640,-640]**
Operation in SPS (from 400.73-400.79 MHz for SPS beams of 120-450 GeV)	[-60, +0]				
		Push-pull tuning	**0.37**	±1.6	**[+310, -310]**



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- Deviations between calculated values and frequency shifts experienced by cavity.
  - **Tuning mechanisms.**
  - **Reviewed Manufacturing and Inspection Plan (MIP)**: measure frequency shifts when possible prior to tuning (e.g. detuning due to coupler insertion before trimming)

- Documentation:
  - *Tuning procedure, Excel files*: to **guide tuning** of cavity at different stages and assuming different scenarios
  - *Traveler*: to **track cavity "frequency trip"** during manufacturing, preparation, tuning and operation

Overview of MIP – *what comes when* *(reduced)*

Detuning due to coupler insertion
Trimming of subassemblies
Final EB weld of the cavity
Bead pull measurement
Bulk chemical polishing
Heat treatment
Pre-tuning
Light chemical polishing
High pressure water rinse
Evacuation and helium leak test
120 C low temperature bake
RF acceptance tests at cold temperature (without and with HOM couplers)

MIP follows all cavity life, from manufacturing of parts, through bare cavity test, to SPS test.

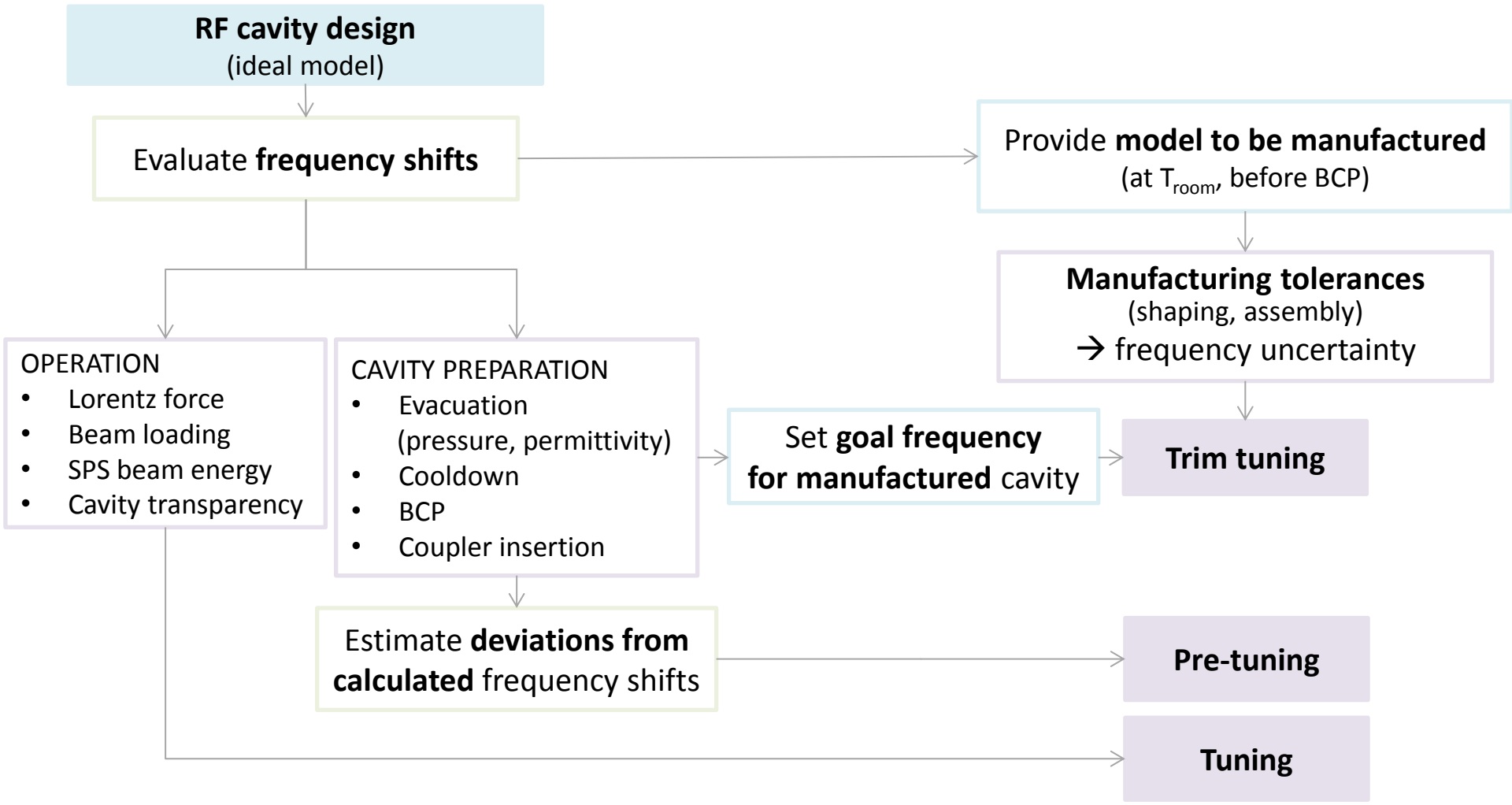
Frequency step		Temp	Pressure		Permittivity (air/vacuum)	Cum. thickness removal	Couplers in (1) / out (0)		RF off/on	Beam off/on
			outer	inner			FPC	HOM		
Step ID	Status / Action	[K]	[mbar]	[mbar]	ε_r	[µm]				
BC-20-QA	*Final EB weld of cavity*	300	1013.3	1013.3	1.00067	0	0	0	off	off
↓										
BC-26-QC	*Pre-tuning with freq check*	300	1013.3	1013.3	1.00067	0	0	0	off	off
↓						↓				
BC-33-QA	*Bulk BCP* (150 µm)	300	1013.3	1013.3	1.00067	150	0	0	off	off
↓										
BC-37-QA	*Heat treatment*	300	1013.3	1013.3	1.00067	150	0	0	off	off
↓						↓				
BC-38-QA	*Light BCP* (30 µm)	300	1013.3	1013.3	1.00067	180	0	0	off	off
↓							↓	↓		
	Assembly test couplers	300	1013.3	1013.3	1.00067	180				
↓				↓	↓					
BC-47-QC	*Evacuation*	300	1013.3	vacuum 0	1	180				
↓										
BC-48-QC	*120°C bake*	300	1013.3	vacuum	1	180				
↓		↓	↓							
BC-49-QC	*Cooldown*	2	30	vacuum 0	1	180				
↓										
	RF on (nominal operation)	2	30	vacuum	1	180				
↓		↓	↓							

Expected frequency shift		Expected frequency after action		Measured frequency after action
		(from simulations)	(corrected from freq measured in previous step)	
Due to…	[kHz]	[MHz]	[MHz]	[MHz]
Last weld-A shrinkage	980.0			
Last weld A sagging	-70.0	400.3431	#VALUE!	
Pre-tune for bare cavity test	0.0	400.3431	0.0000	
Thickness removal	-121.4	400.2217	-0.1214	
*High-T bake***	0.0	400.2217	0.0000	
Thickness removal	-24.3	400.1974	-0.0243	
Test couplers in	0.0	400.1974	0.0000	
Vacuum pressure	0.1			
Permittivity change	133.3	400.3308	0.1334	
*Low-T bake***	0.0	400.3308	0.0000	
Thermal contraction	573.0			
He pressure	-0.1	400.9037	0.5729	
Lorentz force (RF on)	-0.4	400.9033	-0.0004	

Frequency trip control

Traveler to keep track of cavity frequency trip.
May be useful later on for preparation of LHC CCs.
Interesting to also include frequency trip of main HOMs.

How to get cavity “in tune”?



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Overview

- Tuning strategy designed for DQW CC seems to provide enough tuning range given the expected frequency shifts.
- The MIP has been reviewed and modified for enhanced tuning procedure.
- A trim tuning procedure has been proposed; can be tested with LARP cavity parts.
- Documentation to assist trim tuning is being prepared.
- *Cavity parts may be ready by October 2016*… necessity to start preparing tooling and ancillary for trim tuning.
- Tuning methods for pre-tuning before cavity is assembled into vessel are still under consideration and would need further engineering studies if finally chosen.

Thanks for your attention

Comments, questions?

Back-up